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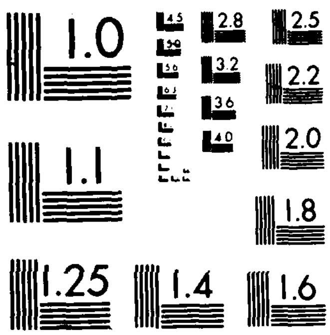

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This investigation reports the heat exhaustion signs and symptoms (SAS) which fourteen healthy, unacclimatized males experienced during 8 days of heat acclimation (HA) in an environmental chamber (41.2 ± 0.5°C db, 39.0 ± 1.7% RH). Daily HA trials consisted of 100 min of intermittent treadmill running at mean (± SE) self-selected exercise intensities of 63.0 ± 2.8 to 71.8 ± 2.9 (range: 51 - 95) %VO_2 max. Typical physiological adaptations to heat occurred. Mean day 1 vs. day 8 values were: final HR = 169 ± 3 vs 144 ± 5 beats·min^{-1}, final Tre = 39.19 ± 0.10 vs 38.55 ± 0.17°C, final Tsk = 37.56 ± 0.21 vs 36.52 ±

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Signs and Symptoms of Heat Exhaustion During Strenuous Heat Acclimation Exercise

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Running Head: Heat Exhaustion and Strenuous Exercise

[5 tables, 1 figure]

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Abstract

This investigation reports the heat exhaustion signs and symptoms (SAS) which fourteen healthy, unacclimatized males experienced during 8 days of heat acclimation (HA) in an environmental chamber ($41.2 \pm 0.5^{\circ}C$ db, 39.0 ± 1.7 % RH). Daily HA trials consisted of 100 min of intermittent treadmill running at mean ($\pm$ SE) self-selected exercise intensities of 63.0 ± 2.8 to 71.8 ± 2.9 (range: 51 - 95) $\%VO_2max$. Typical physiological adaptations to heat occurred. Mean day 1 vs day 8 values were: final HR = 169 ± 3 vs 144 ± 5 $beats \cdot min^{-1}$, final Tre = 39.19 ± 0.10 vs $38.55 \pm 0.17^{\circ}C$, final Tsk = 37.56 ± 0.21 vs $36.52 \pm 0.26^{\circ}C$, $\%\Delta PV = -7.33 \pm 0.89$ vs -5.85 ± 1.31. Mean entering body weight was stable from day 1 to day 8, except that subject N lost 5.44 kg from day 5 to day 8. Subject N was one of four subjects who exhibited a lack of physiological adaptations in HR, Tre, Tsk and $\%\Delta PV$. 12 out of 14 subjects (85.7 %) experienced one or more SAS (e.g. dizziness, chills, abdominal cramps, vomiting). SAS occurred in 20 out of 112 trials (17.8 %). SAS were not more prevalent at high exercise intensities; the greatest number of SAS occurred at 50 - 69 % VO_2max. Correlation coefficients (r^2) of relationships between the number of SAS and physical characteristics were: age - 0.31, height - 0.16, mass - 0.03, surface area - 0.00, surface area/mass - 0.10, VO_2max - 0.01 (all $p > .05$). It was concluded that SAS were not related to physical characteristics, and that the physiological status of subjects at the appearance of SAS varied widely. Furthermore, HA was an important factor in reducing the incidence of SAS (days 1 - 4 = 23, days 5 - 8 = 10).

KEY WORDS: maximal aerobic capacity; heart rate; rectal temperature; plasma volume; running

Introduction

Manifestations of heat illness include heat cramps, heat tetany, heat syncope, heat edema, skin disorders such as miliaria rubra, heat stroke, and heat exhaustion (22). Heat exhaustion is the most commonly recognized heat disorder observed during athletic competiton (25) or military maneuvers (19,21,24), and is the subject of this investigation. Clinical descriptions of heat exhaustion often include various combinations of headache, dizziness, fatigue, hyperirritability, anxiety, tachycardia, hyperventilation, diarrhea, nausea, vomiting, syncope, heat cramps, "heat sensations", piloerection and chills (3,5,6,19,20,25,27,29). This has led Callaham to describe heat exhaustion as a vague syndrome which is best diagnosed by excluding the other heat illnesses (6). Although it is believed that heat acclimatization and physical training decrease the risk of heat illness (1,3,12,20,21,24,29), heat exhaustion may be observed in thoroughly acclimatized or well trained individuals when exercise is performed in a hot environment (7,20,24,25). The role of exercise in the appearance of heat exhaustion signs and symptoms has not been studied systematically, but exercise and metabolic heat production are often described as key factors in exertional heat stroke (13,26). In fact, controlled studies involving any severe form of human heat illness do not exist (6), and our understanding of the heat exhaustion arises primarily from prospective or anectdotal reports (7,11,14,24,25,28).

During the course of an investigation examining heat acclimation by treadmill running (2), several heat exhaustion signs and symptoms (SAS) were observed in 14 unacclimatized volunteers. These SAS were transient, reversible, and resulted in no observable harm to subjects. However, their appearance was valuable because clinicians and physiologists rarely have the opportunity to observe the preliminary clinical course of heat exhaustion, and because individuals who exercise in the heat rely solely upon SAS to gauge the onset of heat injury. The following data clarify the preliminary course of heat exhaustion by describing (1) the status of subjects at the onset of heat exhaustion SAS, and (2) the effects of various factors (e.g. eight days of heat acclimation, exercise intensity, physical characteristics) on the incidence of heat exhaustion SAS. Data are also presented which clarifies the motivation of subjects who reach predetermined heart rate and rectal temperature limits during exercise in a hot environment. Although prior studies have observed HA during walking or cycling exercise in hot environments, the present investigation is one of the first to report HA adaptations resulting from high intensity, self-selected exercise.

Methods

The subjects of this investigation were 14 males, whose physical characteristics are described in Table 1. After informed consent was obtained, all volunteers underwent a physical examination and completed questionaires regarding their medical history, physical activity and prior heat exposure. These forms and outdoor temperatures (below) during heat acclimation (HA) were examined to determine if each subject was unacclimatized prior to this investigation. One day prior to testing, height and weight were measured, surface area was calculated (10), and subjects performed a maximal oxygen consumption (VO_2max) test using the technique described by McArdle et al. (23) with slight modification.

A 20 minute standing equilibration period in the heat preceeded an antecubital blood sample (days 1 and 8) and body weight (BW) each day (Sauter Co., accuracy $\pm$ 10 g). A second antecubital blood sample and body weight were taken immediaely post-exercise. Blood samples were analyzed for microhematocrit and hemoglobin (Hycel Inc.) in triplicate. Changes in plasma volume (%ΔPV) were calculated from changes in hematocrit and hemoglobin (8). Body weight differences were used to calculate sweat rate (SR), and were corrected for water intake and urine output. Ratings of perceived exertion (RPE) were recorded during exercise, using the Borg psychophysiological scale of 6 - 20 points (4).

Each subject underwent eight days of HA via treadmill exercise in an environmental chamber maintained at 41.2 $\pm$ 0.5°C, 39.0 $\pm$ 1.7 %RH. Days 1 and 8 of HA were control trials which allowed pre- vs post-HA comparisons. Days 2 - 7 of HA involved self-selected treadmill running. Two days of rest were taken between HA day 4 and day 5, to simulate a weekend free of training-induced heat stress. Subjects were encouraged to drink adequate water during non-testing hours.

Day 1 and day 8 consisted of identical 100 min control trials. There were nine exercise periods of 5 - 10 min duration, each followed by a standing rest period of 2 - 10 min. The order and duration of exercise-rest periods during HA trials has been previously described (2). On days 1 and 8, subjects walked at 0.95 $m \cdot sec^{-1}$ during the first two exercise periods, at 1.58 $m \cdot sec^{-1}$ during the next two exercise periods, and then performed self-selected running during periods 5 - 9 of all trials. All treadmill speeds selected on day 1 were duplicated on day 8.

On days 2 - 7, subjects were encouraged to jog or run during all nine exercise periods; walking was discouraged unless subjects deemed it necessary because of fatigue or discomfort. An investigator slowly increased or decreased the treadmill speed until the subject signalled. Subjects were allowed to change the belt speed at any time during the trial, but were instructed that expired gas measurements required a steady pace during periods of collection. They were further instructed to set a pace which could be sustained during the 5 min prior to collections. These instructions were intended to preclude running speed changes and investigator exhortations. Treadmill belt speeds were measured during each of 1008 exercise periods (8 days, 9 exercise periods, 14 subjects), using a digital tachometer. Subjects ran in pairs, one subject per treadmill, and were unaware of the actual treadmill speed, HR, or Tre during HA trials. All trials were run on a horizontal grade. The following values were calculated for each subject each day: mean treadmill speed selected, mean $\%VO_2max$ for exercise, and distance run.

A semi-automated system was used to collect and analyze expired gases during each exercise period that involved a change of treadmill speed. A computer (Hewlett-Packard, model 85B), scanner, and digital voltmeter were interfaced with a gas meter (Parkinson-Cowan), oxygen analyzer (Applied Electrochemistry, model S3A), and carbon dioxide analyzer (Beckman, model LB2). Heart rate (HR) was monitored continuously using an ECG telemetry system (Hewlett Packard). Each subject was equipped with a rectal probe (inserted 8 cm beyond the anal sphincter) and three skin probes placed on the chest, forearm and calf. Rectal temperature (Tre) and mean weighted skin temperature (Tsk) readings were recorded every four minutes. Water was drunk <u>ad libitum</u> throughout all trials, but could not be sprayed or poured on the body.

Exercise was terminated if HR exceeded 180 $beats \cdot min^{-1}$, if HR did not fall below 160 $beats \cdot min^{-1}$ during any 5 min period of rest, if TRE exceeded $39.5^{\circ}C$, or if signs and symptoms (SAS) of heat stress warranted premature termination of trials (PTT) in the opinion of the medical monitor. These HR and Tre limits were established by the local Human Use Review Committee, and are referred to as "predetermined guidelines" in this manuscript. If PTT occurred on day 1, an identical trial was performed on day 8. Special emphasis was placed on recording SAS of heat exhaustion during each trial.

Appropriate t-tests, one-way ANOVA, and two-way ANOVA were utilized to compare data at the .05 confidence level. Correlation coefficients were calculated via linear regression analyses to evaluate the relationships between physical characteristics and the number of SAS observed.

Results

Mean daily outdoor maximum temperatures (^oC) for the months of January through May were: -2.8 $\pm$ 0.7, 2.7 $\pm$ 1.3, 8.2 $\pm$ 1.1, 14.1 $\pm$ 1.2 and 20.3 $\pm$ 1.0, respectively. Mean daily outdoor minimum temperatures (^oC) for these months were: -10.4 $\pm$ 0.7, -6.4 $\pm$ 1.2, -2.5 $\pm$ 0.9, 3.0 $\pm$ 0.8 and 8.3 $\pm$ 0.7. These data and questionaires involving prior heat exposure indicated that all subjects were unacclimatized at the beginning of this investigation.

Table 2 indicates that no significant differences were found in group mean entering BW across days 1-8, although a sizeable BW decrease was measured in subject N from day 1 to day 8 (3.62 kg) and from day 5 to day 8 (5.44 kg).

HEAT ACCLIMATION

The mean distance covered on the treadmill each day ranged from 8.279 $\pm$ 0.527 to 9.799 $\pm$ 0.433 km. Treadmill belt speeds each day (running periods only) ranged from 151.2 $\pm$ 6.6 to 169.2 $\pm$ 5.4 m/min. Daily exercise intensities (%VO_2max) for these 14 subjects (mean $\pm$ SE) were measured as follows: day 1 - 71.8 $\pm$ 2.9, day 2 - 63.0 $\pm$ 2.8, day 3 - 65.1 $\pm$ 2.6, day 4 - 67.6 $\pm$ 2.3, day 5 - 69.1 $\pm$ 3.1, day 6 - 68.4 $\pm$ 3.0, day 7 - 68.8 $\pm$ 3.7, day 8 - 71.8 $\pm$ 2.9 %. Exercise intensities on days 2 - 7 were not statistically different ($p>.05$). No significant between-day differences were found in final HR, final Tre, final Tsk and %ΔPV on days 2 - 7 (not shown), indicating that subjects self-selected treadmill running speeds which resulted in statistically similar physiological responses.

Table 3 describes the final HR, final TRE, final Tsk and %ΔPV for day 1 and day 8, to describe the physiological adaptations which occurred during eight days of HA trials. All of these variables significantly changed ($p<.05$) from day 1 to day 8, indicating that this group of subjects were heat acclimated. Individual exceptions are discussed below. There also was a significant expansion of pre-exercise plasma volume (+ 5.2 $\pm$ 1.7%, $p<.05$) on day 8 (not shown), when compared to day 1.

SR on days 1 and 8 were significantly lower than SR on days 2 - 7, reflecting the lower sweating stimulus during walking (periods 1 - 4 on days 1 and 8). No significant differences in whole-body SR were found between days 1 and 8 or between days 2 through 7. The SR for days 1-8 were as follows: 401.47 $\pm$ 34.78, 533.65 $\pm$ 36.53, 529.88 $\pm$ 33.01, 562.70 $\pm$ 28.76, 512.98 $\pm$ 32.83, 613.27 $\pm$ 38.88, 587.17 $\pm$ 37.76, and 380.19 $\pm$ 44.99 $ml \cdot m^{-2} \cdot hr^{-1}$. The fact that the daily mean SR did not significantly increase during HA can be explained by the decreased stimulus (Tre) for thermal sweating from day 1 to day 8 (Table 3). Although SR did not increase, the sweat sensitivity ($ml \cdot {}^{o}C^{-1}$) increased from day 1 to day 8.

SIGNS AND SYMPTOMS

Table 4 illustrates that subjects experienced nine different SAS throughout this investigation; most of these did not result in PTT. Only one case involved clear heat exhaustion symptoms (Subject N on day 8) because subjects continuously communicated with investigators and because HR, Tre and Tsk were monitored closely. Heat exhaustion SAS were recorded (Table 4) during 20 of 112 trials (17.8 %), as follows: flushed skin on head and torso with "heat sensations" - 7, chills - 7, abdominal cramps - 5, piloerection - 4, elevated HR after 5 min of rest ($>$ 160 $beats \cdot min^{-1}$) - 4, "rubbery" legs - 2, vomiting - 2, dizziness - 1, hyperirritability - 1. The number of heat exhaustion SAS was larger on days 1 - 4 (n = 23) than on days 5 - 8 (n = 10). Correlation coefficients (r^2) between the number of heat exhaustion SAS (Table 4) and physical characteristics (Table 1) were: age - 0.31, height - 0.16, mass - 0.03, surface area - 0.00, surface area/mass - 0.10, and VO_2max - 0.01 (all $p > .05$).

Table 5 describes the physiological status of subjects at the onset of heat exhaustion SAS. SAS occurred during periods 6 - 9 on fifteen out of 20 days (75 %). Tre at the onset of SAS were distributed in this way: 37.0 - 37.9^oC = 3, 38.00 - 38.99°C = 13, 39.00°C and higher = 4; these Tre categories were associated with 5, 21 and 7 SAS, respectively. HR at the onset of SAS were distributed as follows: 120 - 139 beats$\cdot$min^{-1} = 2, 140 - 159 beats$\cdot$min^{-1} = 6, 160 beats$\cdot$min^{-1} and higher = 11, data not available - 1. RPE at the onset of SAS were distributed in this manner: 6 - 7 = 1, 8 - 9 = 2, 10 - 11 = 5, 12 - 13 = 5, 14 - 15 = 2, and 16 - 17 = 1. This meant that most subjects rated their exercise as either "fairly light" (RPE = 10 - 11) or "somewhat hard" (RPE = 12 - 13).

Figure 1 presents the relationship between exercise intensity and the appearance of heat exhaustion SAS. This figure illustrates the mean exercise intensity (%VO_2max) of trials involving SAS vs those trials in which SAS were absent.

PREMATURE TERMINATION OF TRIALS

The responsible investigator prematurely terminated trials when Tre or HR reached Human Use Review Committee predetermined guidelines (Tre > 39.5°C, HR > 180 beats$\cdot$min^{-1} during exercise, or HR > 160 beats$\cdot$min^{-1} during rest), or if SAS warranted termination in the opinion of the medical monitor. PTT was applied in 19.6 % (22/112) of all HA trials. PTT data offered insight into the motivation of humans pushing beyond predetermined guidelines during exercise in a hot environment. Six out of 14 subjects experienced PTT on day 1, in comparision to 1 out of 14 on day 8. Also, the number of PTT was greater during days 1 - 4 (n = 16) than during days 5 - 7 (n = 6), indicating that subjects adapted to exercise in the heat by maintaining HR and Tre within predetermined guidelines. Because mean daily exercise intensities were very similar during HA (see above), the authors believe that this was not a learned behavior modification involving treadmill speed selection.

Table 6 describes the physiological status of subjects when PTT occurred. The most common factor precipitating PTT was elevated Tre (66.7 % of all reasons for PTT), while SAS resulted in 16.7 % of all reasons for PTT; HR during rest or exercise precipitated 16.7 % of all PTT. PTT occurred during exercise periods 6 - 9 in 95.5 % of all cases. Twenty out of 22 instances of PTT involved mean trial exercise intensities less than 70 % VO_2max. Subject L experienced PTT during 6 out of 8 HA trials because of elevated Tre.

Discussion

During exercise in the heat, SAS represent early warnings of an effort that will result in collapse. In fact, hot weather training/competition guidelines often encourge athletes to learn the SAS of heat exhaustion (1). In the present investigation, SAS were observed during 17.8 % of all trials. No preexisting causes for SAS were evident in most subjects, and large individual differences in the incidence of SAS were observed, in agreement with the findings of Sutton and Bar-Or (28). Approximately half of the subjects (n = 8) experienced 2 or more SAS (Table 4), but were physically indistinguishable (Table 1) from those subjects (n = 6) who experienced 0 or 1 SAS. When subjects in Table 4 were divided into two groups based on VO_2max, both groups had a similar number of SAS ("low" = 16, "high" = 17). Similarly, Richards et al. (25) also found no common preexisting factor among runners who experienced heat exhaustion during a 14 km footrace. Other researchers, however, have reported that heat intolerance and the predisposition to heat illness are statistically related to VO_2max (30), body mass (28), height (11), age (9), and surface area-to-mass ratio (12).

Bean and Eichna (3) reported that flushed skin on the face and torso occurred in almost all subjects during their first hour of treadmill walking in the heat; this sign disappeared as HA developed. During the present investigation, flushed skin on the head and torso with "heat sensations", and chills were the two most commonly reported SAS (Table 4). Subject M (age 46) was a classical example of this phenomenon as he exhibited flushed skin, piloerection and chills on days 1 and 2. The authors speculate that this vasodilatory response represents the body's attempt to dissipate heat from the highly vascularized head and torso regions, via radiation and conduction. This response occurs until SR maximizes, allowing increased cooling by evaporation. Unfortunately, this increased cutaneous circulation implies that cardiac filling pressure and cardiac output may be compromised. In contrast, England and colleagues (11) reported that the 29 heat injury victims treated at the 1979 Peachtree 10 km Road Race experienced weakness, tiredness and dizziness as their only symptoms. However, it is not clear whether such symptoms result from strenuous exercise, heat, or both. Jones et al. (17) have reported that SAS similar to those of heat exhaustion (e.g. light-headedness, muscle cramps, fatigue, weakness, nausea, vomiting, headache) were present after a marathon which was run in air dry bulb temperatures of 7.9 - 10.8^{o}C.

As a group, these 14 subjects were classified as "heat acclimated" on day 8 because of the statistically significant ($p<.05$) changes in mean HR, Tre, Tsk and %ΔPV (Table 3). However, four subjects (F, K, L and N) exhibited a clear lack of physiological adaptation to heat, in two or more of these measurements. The failure of subjects F, K and L to adapt properly is not explained by the data presented above. Subject N exhibited poor adaptations of HR, Tre, Tsk and %ΔPV (day 1 vs day 8) and accounted for 7 out of 28 total SAS (Table 4). His loss of 5.44 kg body weight in 72 hr (day 5 to day 8) implies that his dehydrated state masked or temporarily negated HA adaptations. The data of Bean and Eichna (3) also demonstrated a relationship between the loss of heat tolerance and the loss of body water. It appears that the insufficient HA adaptations among these four subjects (Table 3) was not closely related to the number of SAS observed (Table 4) because subjects F, K, L and N had 2, 2, 1 and 3 SAS, respectively. A previous study (3) similarly found that the development of heat exhaustion SAS did not retard the rate or decrease the degree of HA. Nevertheless, HA affected the overall incidence of SAS favorably. A casual analysis of Table 4 indicated that the total number of SAS decreased during the eight days of HA (days 1 - 4 = 23, days 5 - 8 = 10), in agreement with previous reports of heat exhaustion (3,24,29). The number of SAS observed during identical trials on days 1 and 8 also indicated a reduction in the number of SAS during HA. Days 5 - 7 accounted for very few SAS, implying that the two days of rest given between days 4 and 5 also may have decreased the incidence of SAS. A previous investigation reported a similar reduction in heat exhaustion SAS, after a weekend of rest and fluids (3).

One would intuitively expect heat exhaustion SAS to be most common during trials which involved high exercise intensities. However, trials in which heat exhaustion SAS occurred (fig. 1), were distributed in essentially the same way that asymptomatic trials were distributed, and were not shifted toward higher exercise intensities. In fact, the greatest number of SAS and PTT were observed in trials involving exercise intensities of 50 - 69 %VO_2max, and most subjects who experienced SAS rated their exercise as "fairly light" or "somewhat hard".

Prospective clinical reports have indicated that heat injuries occur in the latter stages of road races (11,13), probably because of increased heat storage, dehydration and reduced metabolic fuel stores. The present investigation supports these findings in that 75 % of all SAS and 95.5 % of all PTT occurred during the latter stages of daily HA exercise (periods 6 - 9). Another prospective report (16) has indicated that heat injury often occurs among unacclimatized, novice runners. The present investigation supports this finding because PTT was applied more often on day 1 (6/14) than on day 8 (1/14) of HA. The number of PTT on days 1 - 4 (n = 16) also was greater than on days 5 - 8 (n = 6). Although HA improved the ability of subjects to remain within predetermined HR and Tre guidelines, final

HR and Tre values (Table 6) indicated that several trials would probably have resulted in heat exhaustion or heat stroke if PTT had not been applied.

In considering the motivation of humans to reach predetermined HR or Tre guidelines, it is relevant that Shibolet et al. (27) have reported that the individuals who are at greatest risk of experiencing hyperthermia frequently are young, highly motivated, healthy individuals. We hypothesize that this is true because these persons are relatively unaware of the seriousness of their hyperthermia, compared to the familiar sensations of fatigue or exhaustion. Table 6 supports this concept in that elevated Tre was the most common reason that subjects reached predetermined guidelines and PTT; subjects apparently maintained treadmill speeds without attending to internal cues which indicated that they were approaching PTT and predetermined Tre limits. When treating hyperthermia, physicians do not administer sedatives to control pain associated with hyperthermia, because hyperthermia per se is not painful. In fact, exercising hyperthermic humans may experience sensations of euphoria (11,13), causing them to ignore the subtle symptoms of evolving hyperthermia. For a person accustomed to running to the point of exhaustion, the uncommon sensations related to piloerection or chilling of skin may be more discomforting than the sensations of hyperthermia. Similarly, in a decade of research with an animal model for human hyperthermic conditions (15), exercising animals have never exhibited overt signs which indicated that they were any more painfully stressed at Tre of 42°C than at 40°C, or that animals heated passively up to 42.8°C experienced pain or undue stress. Therefore, any consideration of the factors which motivate certain individuals to exercise to a point of hyperthermia should include the concept that humans do not typically perceive their own hyperthermia as a threat to well-being.

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Table 1 - Selected subject characteristics.

SUBJECT	AGE (yr)	HEIGHT (cm)	MASS (kg)	SURFACE AREA (m^2)	SURFACE AREA / MASS ($cm^2 \cdot kg^{-1}$)	$\dot{V}O_{2\ max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)
A	28	175.5	74.62	1.90	255	42.26
B	23	169	69.63	1.80	258	38.77
C	36	173	57.98	1.69	292	38.84
D	35	165	66.00	1.73	262	61.60
E	25	177	75.01	1.92	256	43.35
F	21	183.5	82.48	2.05	249	47.40
G	28	171	66.93	1.78	266	43.60
H	26	185	101.78	2.26	222	40.95
I	19	183	73.11	1.94	265	48.68
J	32	179	85.86	2.05	239	43.11
K	25	187	79.00	2.04	258	60.87
L	22	184	88.26	2.11	239	49.07
M	46	165	85.62	1.93	225	40.42
N	32	180	110.52	2.29	207	41.40
$\bar{x}$	28.4	177	79.77	1.96	250	45.74
$\pm$ SE	1.9	2	3.78	0.05	6	1.96

TABLE 2 - Entering body weight prior to daily exercise-heat exposure.

	Body Weight (kg)							
Day:	1	2	3	4 +	5	6	7	8
Subject								
A	73.75	74.31	74.44	74.30	74.40	74.40	74.03	75.52
B	70.66	70.68	70.42	70.50	70.49	70.17	70.48	70.16
C	58.60	58.72	58.11	58.82	59.17	58.52	59.20	59.00
D	65.55	65.76	65.68	65.44	66.87	66.29	65.89	65.19
E	75.22	75.66	75.45	75.37	75.49	75.91	75.23	74.42
F	82.87	82.63	82.82	82.03	84.38	84.22	83.82	82.50
G	66.64	66.29	66.29	65.84	68.15	67.74	66.90	67.62
H	101.60	102.02	102.98	103.73	104.54	103.80	103.78	103.13
I	74.21	74.77	74.48	74.67	74.74	74.50	75.27	74.42
J	85.63	85.75	85.30	85.21	84.69	85.23	85.09	85.42
K	79.50	79.11	78.72	78.48	80.76	79.16	78.18	77.93
L	88.41	88.61	87.31	86.73	88.09	87.75	86.90	87.20
M	86.34	85.96	85.88	85.70	86.59	85.42	84.59	84.72
N	110.47	109.68	109.58	109.90	112.29	109.40	107.88	106.85
$\bar{x}$	79.96	80.00	79.82	79.77	80.76	80.18	79.80	79.58
$\pm$ SE	3.76	3.73	3.76	3.78	3.86	3.74	3.65	3.60

+ - two days of rest were given between day 4 and day 5 to simulate a weekend without heat exposure

Table 3 - Final HR, Tre, Tsk and %ΔPV at end of exercise on days 1 and 8.

	Final HR (beats·min^{-1})		Final Tre (^{o}C)		Final Tsk (^{o}C)		% Δ PV	
Subject	Day 1	Day 8	Day 1	Day 8	Day 1	Day 8	Day 1	Day 8
A	163	155	38.85	38.10	37.81	34.69	-7.81	-7.14
B	174	119	38.80	37.58	37.95	36.17	-6.72	+1.90
C	172	138	39.67	38.67	38.17	36.18	-12.06	-8.25
D	142	123	39.66	38.63	37.89	35.95	-9.58	-11.52
E	181	157	38.47	37.64	35.93	35.00	-10.89	-3.67
F	168	160	39.13	38.30	36.17	36.57	-1.34	-5.04
G	170	121	39.53	38.07	38.49	36.38	-7.03	-7.83
H	159	114	39.21	37.97	37.89	36.65	-5.29	-3.77
I	183	150	39.47	39.29	---	---	-8.87	-4.84
J	179	134	39.18	38.60	37.88	37.01	-7.89	-8.01
K	179	163	39.34	39.31	37.60	37.20	-9.42	-7.15
L	175	178	39.54	39.32	38.16	38.10	-2.92	-3.39
M	157	145	38.88	38.71	36.85	37.77	-2.19	+3.06
N	170	163	38.90	39.62	37.51	37.13	-10.67	-16.23
$\bar{x}$	169 *	144	39.19 *	38.55	37.56 *	36.52	-7.33 *	-5.85
$\pm$ SE	3	5	.10	.17	.21	.26	.89	1.31

* - $p < .05$

Table 4 - Heat exhaustion SAS observed on days 1 - 8.*

Subject	1	2	3	4	5	6	7	8	Total
	Experimental Days								
A									0
B				l					1
C		a							1
D		a				f			2
E						c			1
F		cp							2
G		h	fch	fch					7
H			f		c		i		3
I								a v	2
J									0
K	p			d					2
L				f					1
M	pcfh	pcf						a	8
N								avl	3
TOTAL	5	8	4	6	1	2	1	6	33

* - heat exhaustion SAS:

f - flushed skin on head and torso with "heat sensations"

c - chills

a - abdominal cramps

p - piloerection

l - "rubbery" legs

v - vomiting and nausea

h - elevated HR during rest (160 beats·min^{-1})

d - dizziness

i - hyperirritability

Table 5 - Measurements taken at onset of SAS on days 1 - 8. Legend same as Table 4.

				Measurements at Onset			
Day	Period of Onset	Subject	SAS	RPE	Tre (^{o}C)	HR ($beats \cdot min^{-1}$)	Tsk (^{o}C)
1*	6	K	p	13	38.20	140	35.94
1*	6	M	p,c,f,h	14	38.00	185	36.16
2	2	M	p,c,f	11	37.55	138	34.98
2	4	D	s	---	38.20	135	35.84
2	6	C	s	---	38.95	157	37.24
2	5	G	h	12	38.30	175	37.45
2	7	F	c,p	11	38.69	160	36.22
3	6	G	c,f,h	8	39.12	181	36.52
3	6	H	f	9	38.76	176	37.25
4	2	B	l	---	37.43	147	36.37
4	4	G	c,f,h	7	38.80	183	35.77
4	8	K	d	16	39.63	159	35.93
4	6	L	f	13	39.33	164	35.62
5	9	H	c	10	38.89	175	36.42
6	9	D	f	---	38.71	180	34.79
6	8	E	c	13	37.42	184	35.22
7	8	H	i	11	38.59	---	37.11
8*	7	N	s,v,l	15	38.14	167	35.65
8*	8	M	s	13	38.71	145	37.48
8*	post	I	s,v	11	39.29	150	36.70

* - includes four periods of walking (see methods)

Table 6 - Measurements taken at PTT.

Subject	Day	Period	Reason for PTT*	Mean trial $\%\dot{V}O_2max$ +	Measurements at PTT: RPE+	Tre (^oC)	HR ($beats \cdot min^{-1}$)+	Tsk (^oC)
A	2	8	Tre	93	++	39.50	174	37.81
C	1	7	Tre	30	++	39.50	++	++
D	1	7	Tre	26	++	39.50	++	++
F	2	8	c,p	57	15	38.89	166	36.85
G	1	8	Tre	27	15	39.50	170	37.83
G	2	5	h	67	7	39.19	184	37.00
G	3	8	h	64	8	39.35	177	36.87
H	2	7	Tre	60	13	39.50	149	37.53
I	1	8	Tre,HR	31	17	39.50	183	37.81
J	4	6	Tre	66	8	39.50	182	37.91
J	7	7	Tre,HR	87	9	39.50	175	35.98
K	4	7	Tre	62	16	39.50	160	35.93
K	5	7	Tre	59	15	39.50	165	37.02
L	1	9	Tre	27	12	39.50	175	38.16
L	3	9	Tre	65	13	39.50	169	36.11
L	4	8	Tre	59	13	39.50	174	37.88
L	5	8	Tre	63	12	39.50	175	37.84
L	6	7	Tre	66	12	39.50	177	37.67
L	7	9	Tre	57	13	39.50	172	37.73
M	1	9	p,c,f,h	24	13	39.00	187	36.69
M	2	8	p,c,f	57	17	38.96	164	36.86
N	8	9	v,a,l	21	13	39.48	163	36.56

* - Legend: Tre - Tre $\geq$ 39.5^oC safety limit; HR - HR $\geq$ 180 $beats \cdot min^{-1}$ during exercise;
h - HR $\geq$ 160 $beats \cdot min^{-1}$ during 5 min rest; c - chills; p - piloerection;
f - flushed skin on head and torso, "heat sensations"; v - vomiting;
a - abdominal cramps; l - "rubbery" legs

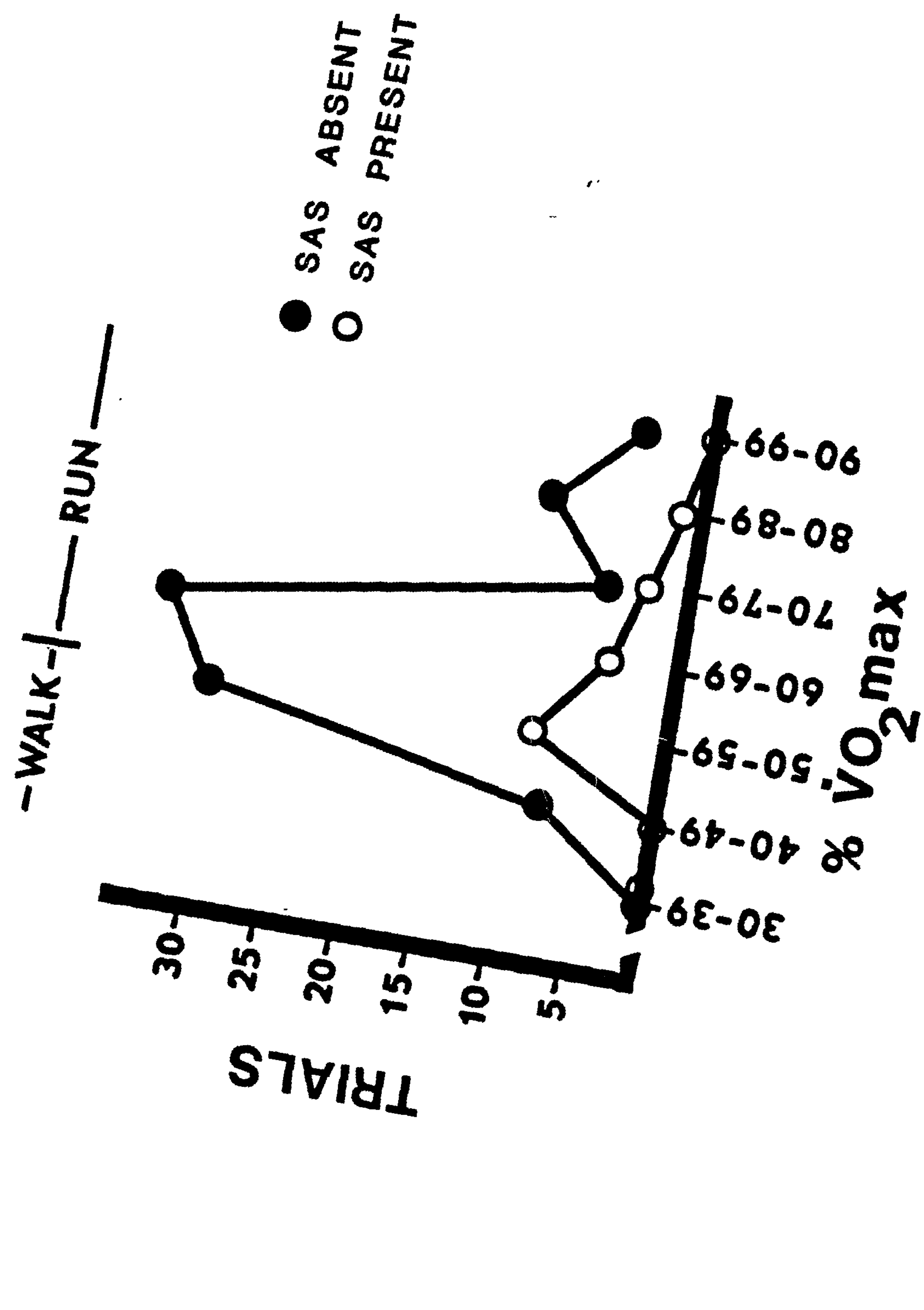
\+ - measured at steady-state during running periods only

++ - data not available

Figure Title

Figure 1 - Distribution of mean daily exercise intensities (%VO_2max) selected by 14 subjects during 112 HA trials.

Figure 1



SAS ABSENT
SAS PRESENT
-WALK-|-RUN-
TRIALS
30
25
20
15
10
5
30-39
40-49
50-59
60-69
70-79
80-89
90-99
% VO2 max

END

1-87

DTIC